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A Comparison of Shear Strength of Box-Section Beam Made of Sliced-Laminated DendrocalamusAsper under Torsion and Transversal Load

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Abstract

This study was purposed to compare shear strength of box-section beams based on torsion test, and shear strength based on four point bending test. Eight beams for torsion test and nine beams for four point bending test of laminated Dendrocalamus Asper (Petung bamboo) bonded with 268g/m^2 of urea formaldehyde were made for this research. The beams were engineered using cool-pressed by 2,0 MPa for 4 hours. The sizes of square-section of the beams are 80mm, 120mm, and 160mm with 15mm, 20mm, and 25mm thick. Based on the torsion test, the research showed that the maximum shear stress was in the range of 4.39 MPa to 10.13 MPa with an average of 6.50 MPa. Shear modulus of the beam was in the range of 690.68 MPa to 1,072.28 MPa with the average of 902.10 MPa. Using four point bending test, the research results showed that the maximum shear stress was in the range of 2.86 MPa to 4.85 MPa with the average of 4.06 MPa. Modulus of elasticity of the beam was in the range of 11,363.37 MPa to 15,739.23 MPa with the average of 13,502.30 MPa. The maximum shear stress based on the torsion test was significantly differed to the maximum shear stress based on the four point bending test.

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Keywords: Box-section; Dendrocalamus Asper; Laminate; Shear.

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1. Introduction

The box-section beam as shown in Fig. 1 has advantages over a solid-section beam due to the same cross-sectional area of the beam has a greater moment of inertia [1]. However, research on the behavior of the box-section beam is still limited.

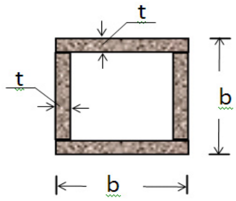

Fig. 1. Cross section of a box beam

A Beam structure can undergo a variety of stresses including shear stress. The shear stress can be caused by twisting loads or transverse load. A study by [2] concluded that the shear stress derived from torsion test differ significantly with shear stress obtained from the four point bending test for Douglas-fir wood beams. Based on the study the researchers wanted to test whether the shear stress at the box-section beams of laminated bamboo also behaves as above. For a box-section beam with a ratio between cross-sectioned width and thickness of the wall minimum equal to 2, formulas derived by [3] are used. The relationship between shear stress (τ), Torque (T), wide cross-section (b), and wall thickness (t) is formulated by,

$$\tau_{\max} = \frac{T}{W_T} \tag{1}$$

$$W_T = b^3 \left(1.864\left(\frac{t}{b}\right) - 5.340\left(\frac{t}{b}\right)^2 + 4.984\left(\frac{t}{b}\right)^3 \right) \tag{2}$$

While the shear stress due to the four point bending testis calculated by the formula,

$$\tau = \frac{VQ}{Ib} \tag{3}$$

where V is shear forces, Q is the first moment, I is moment of inertia, and b is the appropriate width.

2. Materials and Methods

Dendrocalamus Asper for the experiment taken from Malang, East Java, Indonesia, which have been grown for 3-4 years. The Bamboo then formed into a rectangular cross-section sliced with 5 mm thickness, 20 mm width, and 3 m length. Given the bamboo wall thickness varied from bottom to top, a sliced with 5mm of thickness was taken from the part that is closest to the skin. It is expected that the sliced have nearly uniform physical and mechanical characteristics. The sliced were preserved by soaking it in a mixed solution of tetra sodium borax ($Na_2B_4O_2$) and boric acid (H_3BO_3) with a concentration of 2% for 24 hours.

For both types of loading, the specimen cross-section has the same size and made in three sizes of wide section (b): 80mm, 120mm, and 160mm. The wall thickness (t) was made in three sizes: 15 mm, 20 mm, and 25 mm. The span of the beams for torsion test was set eight times of the size of the wide section and for the four point bending test, the span length was set 15 times of the size of the wide section. To support beams during testing, additional 2 x 100mm of length was added.

The beam walls were made of sliced bamboo and were glued to each other as shown on the Fig. 2. Bonding was done with urea formaldehyde at the application rate 268g/m^2 and was engineered using cool-pressed by 2.0 MPa for four hours. The numbers of specimen are eight beams for torsion test and nine beams for four-point bending test.

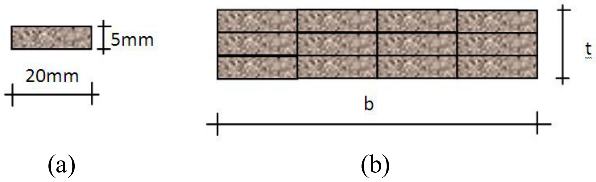

Fig. 2. (a) sliced bamboo, (b) laminated bamboo

Torsion testing was done by referring to the ASTM Standards Volume 4:10: D 198-02 of the Standard Test Method of Test Statics Lumber in Structural Sizes, Section 36-43 [4]. Two types of support were needed during testing: a fixed support and a spinning support to apply torque. The torque was generated from the hydraulic jack with capacity of 5ton, with 400mm long arm twisting. In order to measure the angle of twist, two inclinometers were placed at distance b from the ends of the support as shown in Fig. 3.

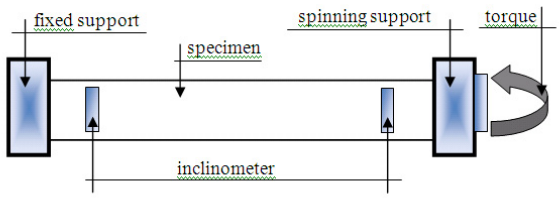

Fig. 3. Torsion test set up.

Four point bending test was done by referring to the ASTM Standards Volume 4:10: D 198-02 of the Standard Test Method of Test Statics Lumber in Structural Sizes, Section 4-11 [5]. Two type of support were needed during testing: a pinned support and a roller support. The transversal load was generated from the hydraulic jack with capacity of 5ton. The middle span deflection was measured with an LVDT as shown in Fig. 4.

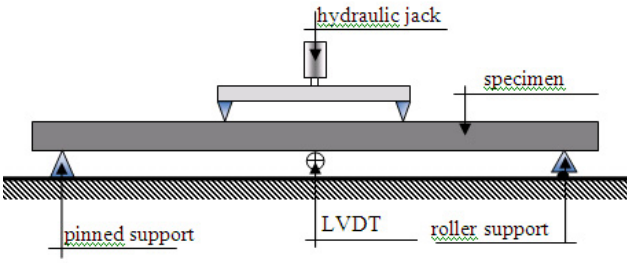

Fig. 4 Four point bending test set up

Loading procedure was conducted from zero torque or load and was gradually increased until the beam collapsed. The magnitude of load versus the deflection at middle span and the magnitude of the torque versus the angle of twist were simultaneously recorded and graphed. From the graph obtained important properties of the beam: proportional limit, the linear part, elastic modulus, shear modulus, and ultimate load.

3. Result and Discussion

3.1 Maximum Shear Strength

The maximum shear stress that occurs in the beam from torsion test varied from 4.39MPa to 10.13MPa with a mean of 6.50MPa and standard deviation of 1.91 MPa. The maximum shear stress that occurs in the beam from four point bending test varied from 2.86 MPa to 4.85 MPa with a mean of 4.06 MPa and standard deviation of 0.58 MPa (Table 1).

The mean shear stress from the four point bending test is 38.05% less than the mean shear stress from torsion test. According to the test, the shear stress of the four point bending test differ significantly to the shear stress of torsion test at a significance level (α) 0.05%. The difference results between two methods mainly caused by the different test set-ups produced different stresses combination. The torsion test produces pure shear stresses and the four point bending test produces combination shear stress and bending stress. The presence of another stress might affect to the shear stress at failure in the beam.

The magnitudes of the shear stress variations were caused by variations in the strength of sliced bamboo that was made up the beam. Data of shear stress parallel to grain of Dendrocalamus Asper from three researchers that collected by [6] showed that the ranges of shear stress were extended from 5.35MPa to 14MPa. Furthermore [7] examined the boards of laminated dendrocalamus asper with the mean shear stress of 7.32MPa.

Table 1. Experimental result

Loading		Shear stress at proportional limit (MPa)	Maximum shear stress (MPa)	Shear modulus (MPa)	Modulus of elasticity (MPa)
Torsion load	min.	1.45	4.39	691	-
	max.	3.70	10.13	1,072	-
	mean	2.34	6.50	902	-
	st.dev.	0.72	1.91	130	-
Transversal load	min.	2.17	2.86	-	11,537
	max.	2.83	4.85	-	15,739
	mean	2.57	4.06	-	13,522
	st.dev.	0.20	0.58	-	1,480

3.2 Ratio shear stress at proportional limit to maximum shear stress

The mean shear stress at the proportional limit from torsion test results 36% below the maximum shear stress and the mean shear stress at the proportional limit from four point bending test results 63% below the mean the maximum shear stress.

A study by [8] found that mean shear stress at the proportional limit is 30% below the maximum shear stress in the torsion test for wood Sitka spruce (Piceasitchensis) and Norway spruce wood (Piceaabies). Furthermore [9] found that the range of the bending stress at the proportional limit is between 33.33% - 50% below the maximum bending stress in the four point bending test for parallel strand bamboo.

3.3 Ratio modulus of elasticity to shear modulus

With a mean of 13.522 MPa modulus of elasticity (E) and shear modulus (G) of 902 MPa is obtained ratio of E : G is 15:1. The ratio is smaller than that used in [10] for wood that is equal to 16:1. A study of laminated veneer lumber (LVL) from southern pine wood obtained the ratio between E and G with a range from 16: 1 to 27.1: 1 [11]. E and G in the study were tested in three different ways, namely three point bending, torsion, and five-point bending.

4. Conclusion

The study of box-section beams of the laminated dendrocalamus asper shows that,

1. The maximum shear stress from the torque test is higher than the maximum shear stress from the four point bending test.

2. The ratio of the shear stress at the proportional limit to the maximum shear stress from torsion test is lower than the ratio from four-point bending test.

3. The ratio of the modulus of elasticity from the four point bending test to the shear modulus from torsion test is lower than a similar ratio used in European Regulation for structural timber.

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